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NRL REPORT 3807

15 Jun 51

LONG-RANGE SEARCH SONAR
PART II. THE 10-KC SYSTEM

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NRL REPORT 3807

LONG-RANGE SEARCH SONAR
PART II. THE 10-KC SYSTEM

H. L. Saxton, M. S. Wilson, and H. R. Baker

June 15, 1951

Approved by:

Dr. E. O. Hulburt, Director of Research

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ABSTRACT

The 10-kc transducer, the central element of the long-range search system, has an active crystal area of about seven square feet – more than four times that of the largest fleet searchlight transducer – and can, with an input of 40 kw, radiate in an 18° beam 24 kw of acoustic power – about 500 times that obtained with conventional equipments. It is accessibly mounted in its protective dome on the forward deck of the U.S.S. GUAVINA. Controls (automatic as well as manual), monitors, display consoles, recorders, playbacks, and power generators are located in the forward torpedo room.

The system will be used to record data, at various depths and in a variety of sea and water conditions, in order to increase ranges and to permit the design of more effective underwater sound equipment for the fleet.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem S07-12R
NR 527-120

Manuscript submitted for publication: April 12, 1951

LONG-RANGE SEARCH SONAR
PART II. THE 10-KC SYSTEM

BACKGROUND

The 10-kc long-range search equipment has been installed in the U.S.S. GUAVINA.[1] Although this equipment is an interim equipment in the over-all long-range search program of the Naval Research Laboratory, its parameters[2] have been chosen so that a pronounced increase in detection range is to be anticipated. The equipment was originally aimed at giving a 14,000-yard detection range whenever a low noise background and a good acoustic path existed. Controllable depth will enable exploration of the ocean for good acoustic paths.

In 1948, analysis based on theory and data then current predicted the failure of any sonar echo-ranging detection equipment to yield consistently a range of 12 kiloyards. It was clear, even then, however, that equipment capable of very long ranges when favorable acoustic paths were present, could be designed and built.

During 1949 and 1950, the Naval Research Laboratory engaged in a series of field trips devoted to propagation studies in which favorable acoustic paths were invariably observed.[3, 4, 5] Studies of sound channelling in mixed surface layers in the ocean have uncovered many pertinent facts concerning this channelling. Such channels are exemplified by path (a) in Figure 1. It has been observed that surface-bounded channels frequently exist, and provide the best paths to targets in the mixed layer out to 20,000 yards in low sea states. Furthermore, optimum transducer depth has been determined for the noise-limited case.

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[1] *Installation of the LRS System in a submarine was planned from the beginning of the problem, not because it is a prosubmarine system, but because a submarine platform offers control of depth which is not so readily provided on a surface ship. The topside mount also affords accessibility.*

[2] *Saxton, H. L., "Factors Influencing the Design of Long-Range Echo-Ranging Equipment," NRL Report S-3467, 16 May 1949*

[3] *Urick, R. J., "Sound Transmission Measurements at 8 and 18 kc in Caribbean Waters, Spring 1949," NRL Report 3556 (Confidential), 11 November 1949*

[4] *Urick, R. J., "Sound Transmission Measurements in the Long Island – Bermuda Region, Summer 1949," NRL Report 3630 (Confidential), 18 January 1950*

[5] *Urick, R. J., "Sound Transmission to Long Ranges in the Ocean," NRL Report 3729 (Confidential), 6 September 1950*

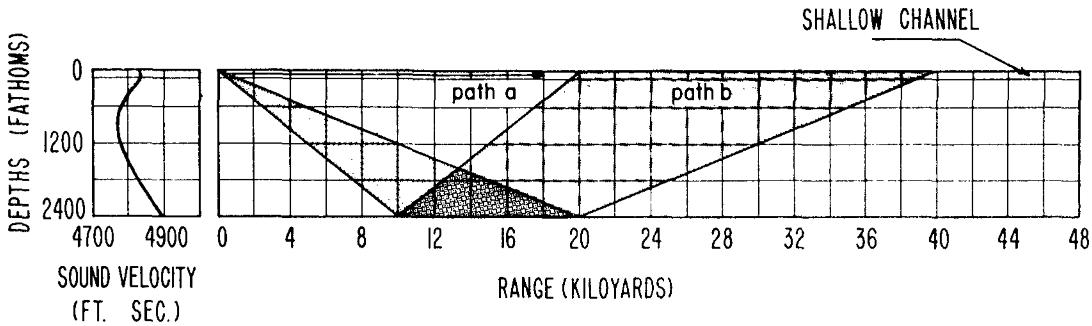

Figure 1 - Paths to targets at all depths

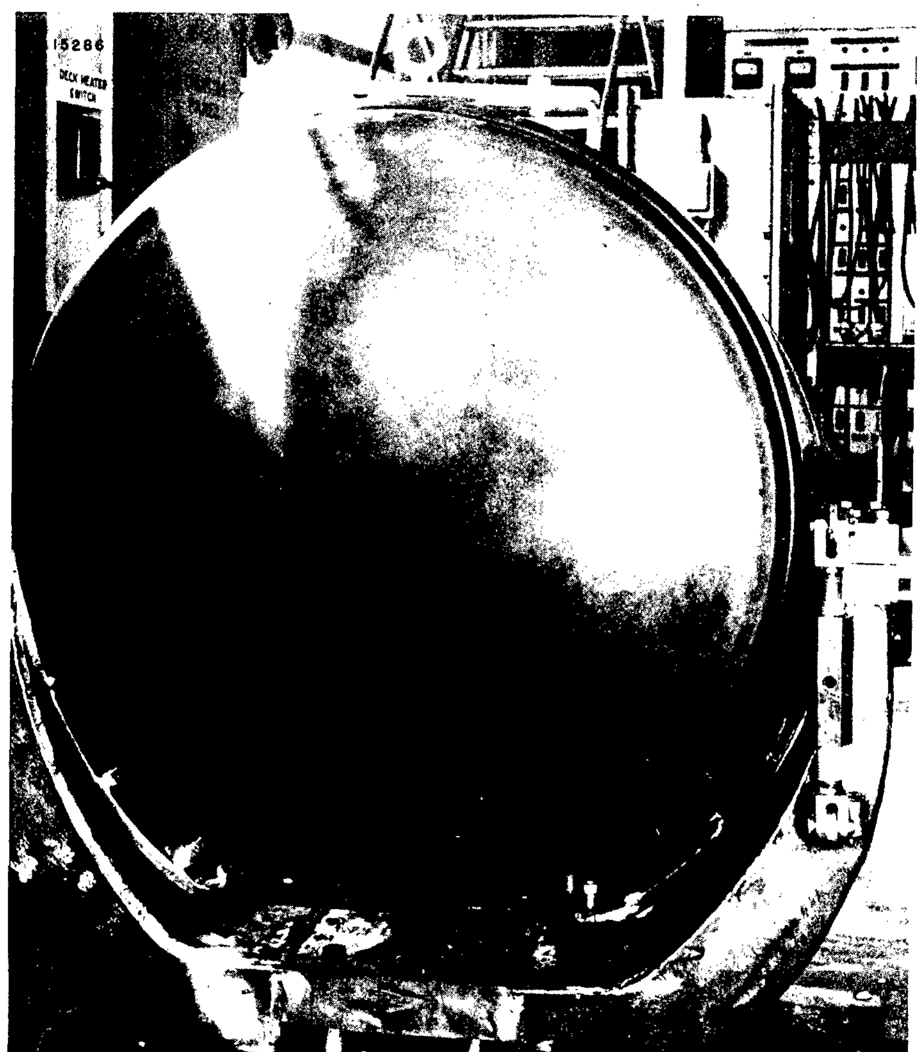

Figure 2 - Assembled transducer

Over paths via the bottom (Figure 1, path b) out to 28 miles, propagation losses have been determined to be those of spherical divergence plus an absorption substantially less than the attenuation obtained by extrapolation and used in the 1948 analysis. (Absorption between 5 and 10 kc is $0.01f^2$ db/kyd, f being the frequency in kilocycles. The values used in the 1948 analysis were obtained from the formula $0.075f^{1.3}$, which is 50 percent too high at 10 kc.)

Because of the apparent dependability of the path via the bottom, and because this permits reaching targets both in and out of the mixed surface layer, it is now anticipated that this path will be primarily exploited. Because of the low measured absorption at 10 kc, the 10-kc equipment is now regarded as aimed at a 20,000-yard range with a low noise background, or a 15,000-yard range with the background of a 15-knot destroyer. Reverberation limitation may appreciably reduce this range in the higher sea states with target doppler-shift less than 1 knot. Current knowledge of reverberation does not permit more accurate predictions.

FULFILLMENT OF REQUIREMENTS

In footnote 2, the requirements for a long-range equipment were listed as the use of low frequency, large transducer area, high power, and improved recognition. The frequency of 10 kc is low enough to reduce attenuation to about a quarter of that at 25 kc. The transducer area is about 7 square feet – nearly four times that of the largest fleet searchlight transducers. The transducer (Figure 2) will handle 40 kilowatts input in half-second pulses and the power supply and driver provide this much power. The efficiency of the transducer is 60 percent. This permits radiating up to 24 kw of acoustic power. With such power, the axial sound intensity is about 500 times that obtained with conventional equipment. If cavitation is to be avoided, however, the full power output can be used only at transducer depths exceeding 100 feet. The recognition differential has been improved by several decibels over that of the ear by scanning the outputs of multiple narrow-band filters. Integration over multiple pings should produce a further gain of several decibels.

DESCRIPTION OF THE SYSTEM

To accommodate the necessary equipment, the greater part of the forward torpedo room of the GUAVINA was made available for the installation (the forward torpedo tubes had been removed in a previous SSO conversion). The forward torpedo room (Figure 3) is, for practical purposes, a shipboard sonar laboratory. It contains all of the long-range search system except the topside installation (also shown in Figure 3).

The system (see Figure 4) is comprised of: (a) a dome, (b) a transducer, (c) a search-control and training equipment, (d) a pulse generator and amplifier with ODC, (e) signal processors, (f) displays, (g) a power control and distribution system, and (h) an equipment monitor.

Transducer and Dome

The transducer and dome are mounted topside, outside of the pressure hull (Figure 3). The transducer and its mounting yoke (Figure 2), together weighing 3000 lbs, are mounted on the standard WFA topside training shaft. The standard carbon bearings in the WFA shaft have been replaced by Goodrich Cutlass bearings. In normal operation, the beam axis of the transducer

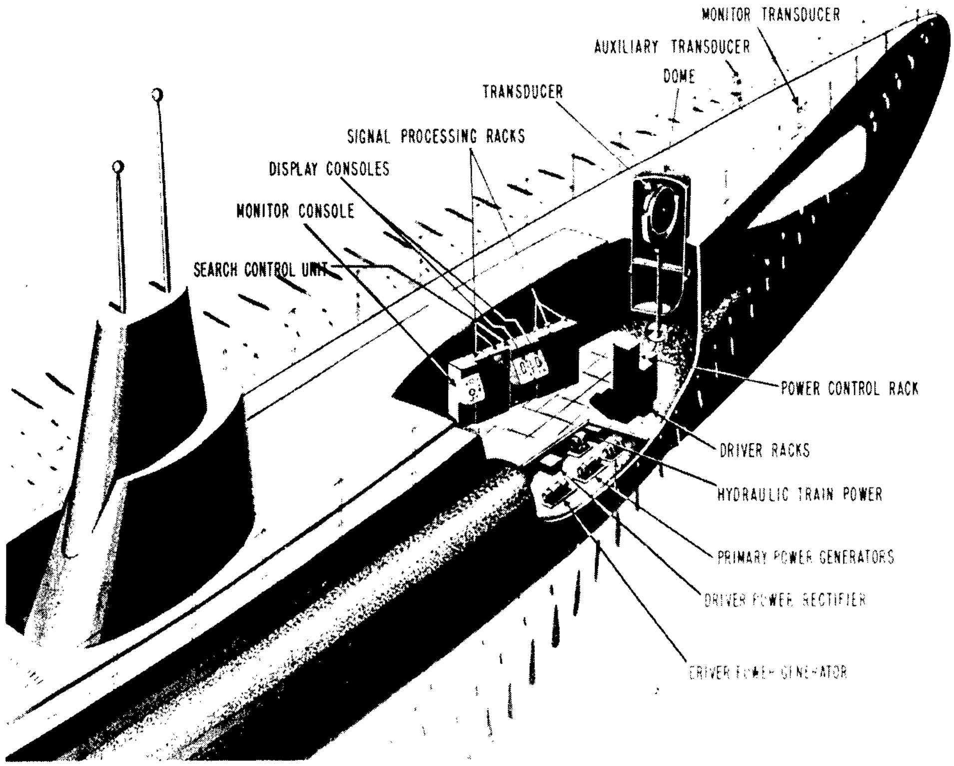

Figure 3 - Location of components in forward torpedo room of U.S.S. GUAVINA

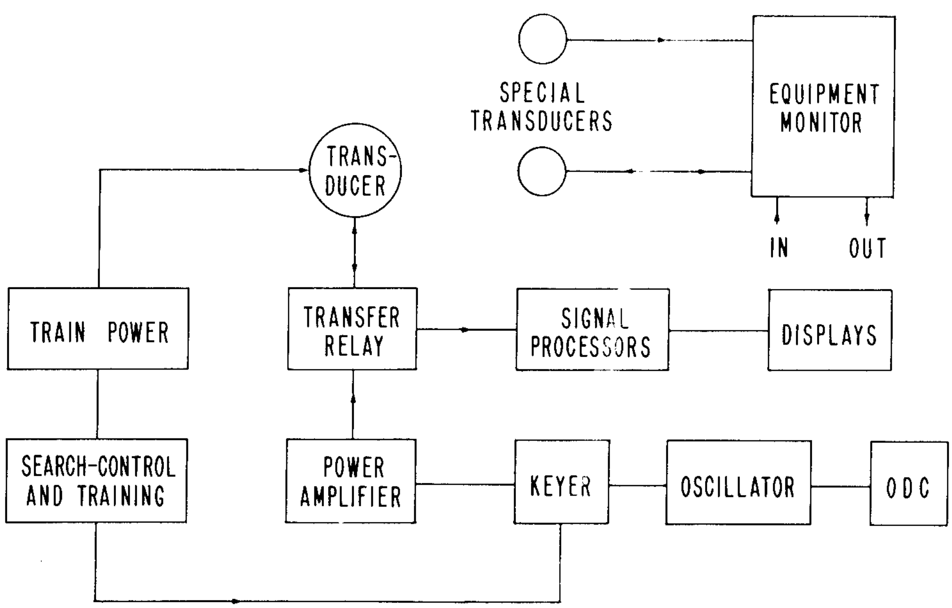

Figure 4 - Major components

is horizontal, but can be tilted manually to a maximum of 30 degrees in 5-degree steps. Tilting is accomplished by a turnbuckle arrangement which can be reached by removing an access door on the dome. Training in azimuth is accomplished, manually or automatically, by the search-control and training equipment.

The transducer employs ADP crystals in its 3-ft-diameter active face. The crystals are arranged in four vertical strips which may be so phased as to steer the beam in a desired manner.

A cylindrical free-flooding dome, 5 ft in diameter and 8 ft high provides protection for the transducer. The dome (Figure 5) is constructed of an inner and an outer grid with a 36-mil sheet-stainless-steel skin spot-welded to the latter. A door facing aft permits access to the transducer without removing the dome. Measurements show a transmission loss of half a decibel through the dome and negligible distortion of the beam pattern.

Search Control and Training

The search-control unit is located above the display console 1 (Figure 6). A control operator may select either manual or automatic operation. In either mode of operation, range may be selected by adjustment of the Long – Short switch and the range-selector knob. Any range from 2.5 to 15 kyds in 2.5-kyd steps in the short-range position and from 5 to 30 kyd in 5-kyd steps in the long-range position may be selected. Automatic control of the repetition rate of the pings and of the returns of the cathode-ray-tube range sweeps (whether or not full-scaled deflection has been obtained) corresponds to the selected range.

In the manual mode of operation, the operator trains the transducer with the handwheel shown at the lower right of console 1. He may observe the true and relative bearing on the indicator directly above the handwheel. Before switching to automatic operation, the control operator should train the transducer until the center-of-search-arc dial (directly above the bearing-indicator dial) indicates the desired center. He may then throw the switch to Automatic.

Having already selected the range and the center bearing of the search arc, the control operator still needs to set up the search arc from 90° to 180°, and the ping arc (arc traversed between successive pings) from 3° to 9°. The transducer then automatically scans continuously back and forth over the selected search arc at a rate which traverses the selected ping arc in the time determined by the selected range.

A Mark 5 Mod 9 hydraulic train unit is installed beneath the deck of the forward torpedo room. This unit contains its own amplifier and trains the transducer in whatever program is set up in the search-control unit.

Pulse Generation and Amplification

The signal to be transmitted originates in an electronic oscillator. An own-doppler-compensation unit varies the normal 10-kc frequency as own-ship's speed and transducer-train angle are varied. The correction is such that volume reverberation always appears at the same center frequency. A keyer unit forms a signal pulse from 0.1 to 0.5 sec in length, and delivers this pulse to the amplifier.

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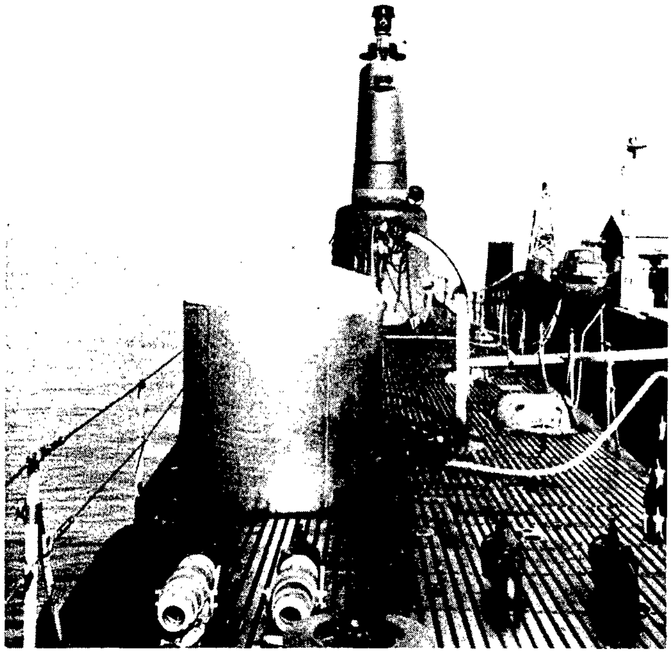


Figure 5 - Dome

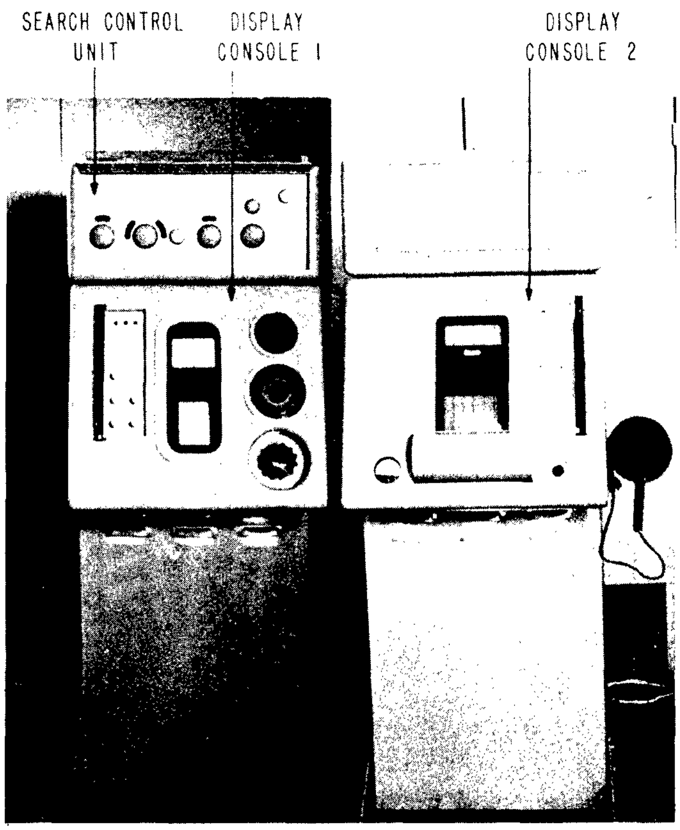


Figure 6 - Display consoles and search-control unit

For electrical signal outputs up to about 4 kw with a pulse length of 0.5 sec, a low-power unit is the only amplifier employed (right rack of Figure 7). This amplifier receives its plate power from a conventional rectifier circuit with capacitors providing electrical storage. (With shorter pulses higher power may be obtained.)

When high power is desired, the low-power unit is used as a driver for an added final amplifier (left rack of Figure 7). This final amplifier is designed to deliver up to 40 kw in a 0.5-sec pulse at 10 kc. The dc energy used by this final amplifier at each pulse may be as high as 40 kilowatt-seconds. This energy is stored mechanically in a flywheel mounted on a special motor-generator set. The 3-phase ac output of this set is converted to high-voltage direct current in a conventional three-phase full-wave rectifier system. The duty cycle at maximum pulse energy is 1/30. If a higher duty cycle is required, either the pulses must be shorter or the power must be reduced.

Except in the output circuit, tuning is omitted from the amplifier stages, making it possible to operate over a band of frequencies limited only by the frequency characteristics of the transducer. Means are provided for measuring the transducer current, which may be adjusted to any desired value up to the maximum safe value for the transducer.

Signal Processing

Electric signals from the transducer's vertical sections are used as inputs to a receiving isolation amplifier whose function is to combine the energy from the transducer elements providing electrically independent outputs to the various signal-processing devices described below.

A conventional 10-kc receiver is used as a standard with which to compare other receiving equipments. Different bandwidths from 50 to 200 cps may be selected, and spot-tuning in 50-cycle steps may be accomplished when the 50-cps bandwidth is used. The receiver output goes to a distribution panel, from which it may be connected to headphones at the operators' consoles, to a loud speaker, and to cathode-ray-tube displays.

The sector-scan indicator (SSI) is a phase-sensitive receiver which measures the phase angle between the electrical outputs of the two halves of the transducer. In the field, and simultaneously in the laboratory, this device will be further developed to bring out its optimum detection possibilities. The

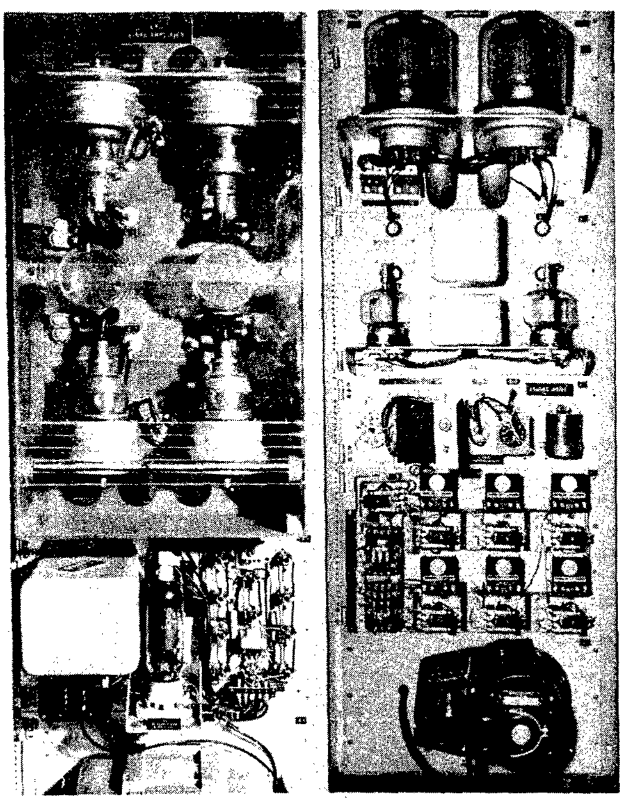


Figure 7 - High- and low-power amplifiers

SSI assists in holding a target on the beam axis of the transducer and may be useful in target classification.

The frequency-scan receiver employs scanning of the outputs of multiple narrow-frequency bands, which together cover the range of frequency required to accommodate doppler shift. Each channel rejects a large part of noise in the whole reception band. This receiver has proved in previous field tests to offer a high sensitivity against a noise background, or, in the presence of a slight target doppler shift, against a reverberation background.

The sum-and-difference receiver may be employed to process two slightly different frequencies transmitted either simultaneously or in time sequence. In the latter case, the returns are recorded on magnetic tape and then played back with different time delays to reproduce returns from the same area simultaneously as inputs to the receiver. Other processing devices will be used with recording and playback for as many as 8 pulses on different frequencies in a time sequence.

The range-rate indicator, a relatively new development, will be utilized to study the nature of echoes and interference, and for target classification, and will be further developed to bring out its detection capabilities.

The advantage of dividing the search area into a multiplicity of smaller areas and integrating successive returns from these smaller areas to the exclusion of all else, is recognized and exploited in the program of sweep-ping procedure combined with range-gating and integration over three or more successive pings. Overlapping sectors are insonified at different frequencies in a time sequence to permit three or more pulses to be on their way simultaneously. A special receiver is gated in range. Each of the channels of this receiver integrates over three or more successive returns in the same range gate on overlapping sectors. An appreciable gain in sensitivity has been experienced in the laboratory and is anticipated in the field. Outputs may be used to actuate an automatic alarm.

Displays

The control operator, who is seated in front of display console 1, has before him, in addition to the search controls and indicators previously described, the displays of the frequency-scan receiver and of the sector-scan indicator (Figure 6). Both are B-scans, the former plotting frequency of the returned signal against range, and the latter plotting bearing deviation from the transducer beam axis against range.

A second operator observes the displays of console 2 (Figure 6). The upper of these is an A-scan which indicates signal amplitude versus range. The lower display is the electronic range recorder, which utilizes the long persistence of a dark trace tube in a presentation of echo and background over periods up to one hour. The trace is a succession of horizontal lines, one for each ping, displaced vertically in a similar manner to the lines on a conventional range recorder. Echoes produce spot-darkening. Time integration over any number of pings is available. Erasure may be accomplished in 15 seconds.

Power Control and Distribution

One 8-kva generator supplies power to the driver; another supplies power for all other electronic units. Power controls and switches for the distribution of the power to all units of the system are located on a central distribution panel.

A 40-wire power-distribution panel is attached to the back of each rack, a single cable from a 40-wire junction box on the main power control panel is run to the first rack, and short cables of the same type are run between the distribution panels on the back of each rack. All ac power is distributed from these panels to the various components of the system.

Equipment Monitor

Results obtained with sonar equipment depend upon equipment characteristics, self-noise, target characteristics, and the nature of the medium – any one of which may change with time. While conducting operational performance research with a system, it is paramount that these parameters be measured quantitatively. In the long-range search system, instrumentation for their measurement has been included as an integral part of the system.

The equipment monitor consists of a B-19-H hydrophone mounted topside in the same horizontal plane as the axis of the main sound beam when the transducer is not tilted, and a monitor console (Figures 3 and 8) in the forward torpedo room containing circuits for the transmitting and receiving functions and containing the displays.

As a receiver (Figure 9), the monitor will receive energy from the echo-ranging transducer and display the pulse power, pulse shape, pulse length, and the wave form of the individual cycles making up the transmitted pulse. The transducer beam pattern may be plotted by the monitor. Also the frequency of the echo-ranging driver oscillator may be measured directly.

As a transmitter (Figure 9), the monitor will generate and transmit the signals illustrated. These signals may be transmitted through the water or directly to the input of the signal processors. A calibrated c-w signal is supplied for alignment of the echo-ranging receivers. Simulated echoes of known target strength and doppler shift are provided. Signals are generated for the calibration of noise, reverberation, and echo levels. The receiving beam-pattern of the system's transducer may be recorded on a beam-pattern plotter.

This monitor will facilitate the objective evaluation of the experimental sonar system, and will make for economy of operational time and facilities by providing accurate checks on the system performance; and by providing a means for measuring noise, reverberation, and echo levels.

SONAR REPEATER

A parameter which must be considered in evaluating the echo ranges obtained is target strength. It is well known that the sound energy reflected from a submarine target in a given direction varies with the target's aspect and with other target characteristics. For use in acquiring a better understanding of the phenomena associated with the long-range detection problem, a sonar repeater, which will provide a constant target strength at any desired level, has been designed for use with the 10-kc system. The repeater consists of a hydrophone to be lowered from a surface vessel to any depth down to 1000 ft, and the associated electronic and recording equipment. Energy received from the 10-kc system is recorded and reradiated at a known and controllable gain (calibrated in terms of target strength) after a slight time delay. The integrity of the energy envelope is preserved in the repeated signal, except that a provision is made for introducing slight frequency shifts.

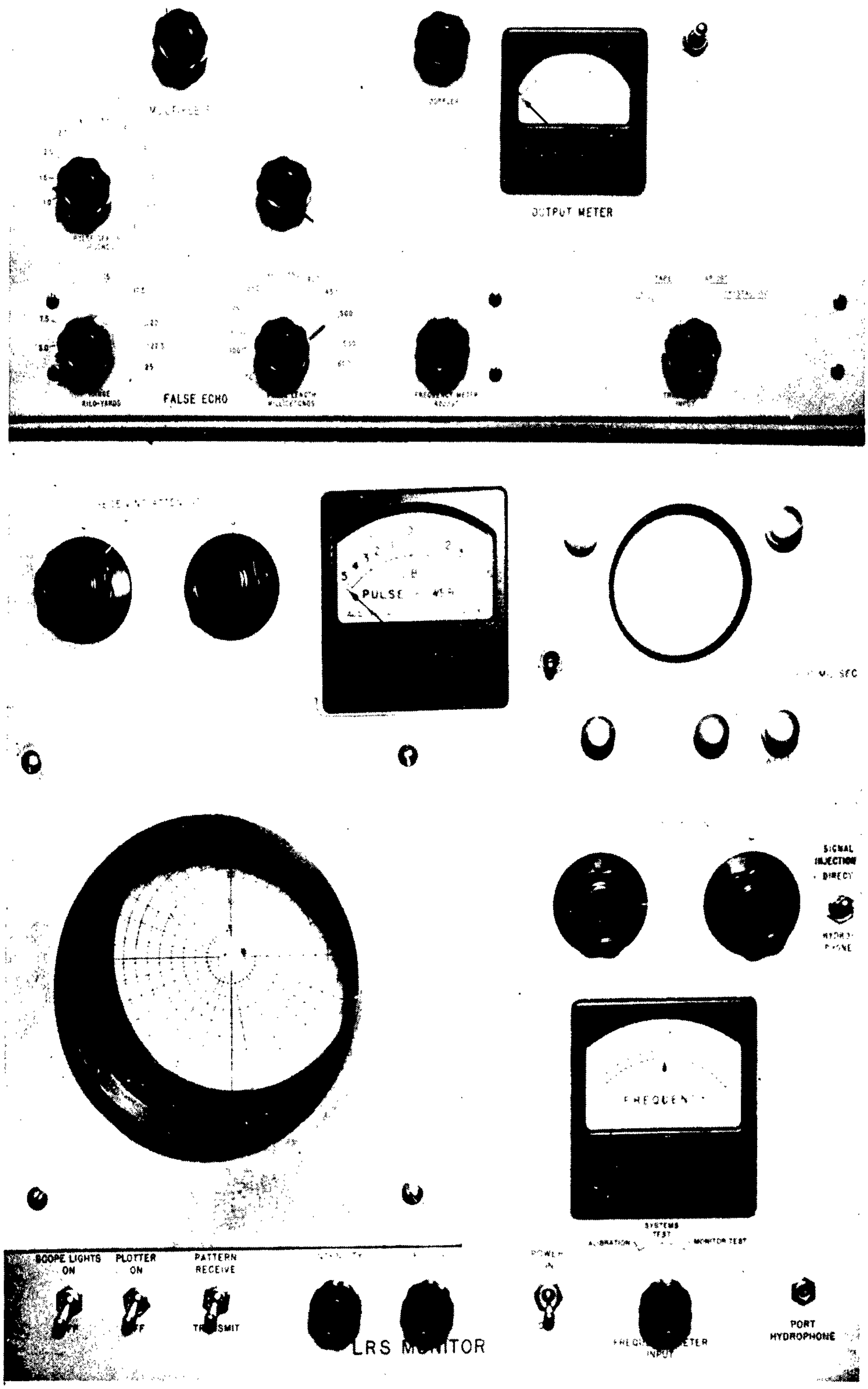


Figure 8 - Control unit and console 1 display

UTILIZATION FOR RESEARCH

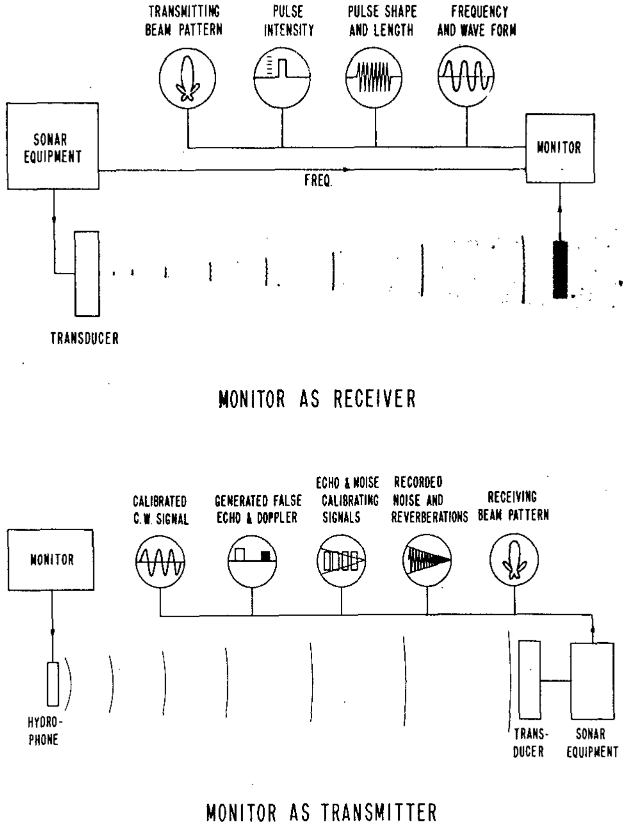
As a result of the knowledge gained in previous research in the design and development of this system, the system now becomes an instrument for extending research. Further research and development objectives are:

(a) The determination of optimum equipment components which involves calibration of standards, and quantitative measurements of the performance of alternative components;

(b) Studies of the oceanographic factors which obstruct or permit long ranges, with emphasis on reverberation measurements at long-range measurements which would be impossible without utilizing high-power equipment;

(c) Studies of operator factors; and

(d) The development of checks on system performance, including performance of the ocean as a medium.



MONITOR AS RECEIVER

MONITOR AS TRANSMITTER

Figure 9

It is intended that the performance of all components of the system, the medium, and the target, be definitely pinned down under a wide variety of conditions. Effects of the interaction of transducer depth, temperature distribution, and transducer tilt, on signal, noise, and reverberation levels will be observed. Signal fluctuations will be studied and interpreted, if possible, in terms of the characteristics of both target and medium.

FUTURE PROGRAM

When a selection of optimum components has been made, and if the system gives substantial day-to-day detection ranges in presently assigned testing areas, the equipment should be operated in strategic areas of the ocean in different months to determine its full potentialities.

It is planned to report results as rapidly as they are obtained. In this way the latest data will be available to contribute to the design of modern fleet equipment even before this research program has run to a natural conclusion.

* * *

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(NRL REPORT 3807)

LONG-RANGE SEARCH SONAR - PART II - THE 10-KC SYSTEM

SAXTON, H.L.; WILSON, M.S.; BAKER, H.R. 15 JUNE'51 11PP
PHOTOS, DIAGRS, GRAPH, DRWG

SONAR EQUIPMENT

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7103/130

DATE: 12 November 1996

FROM: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

TO: Code 1221.1

VIA: Code 7100

REF: (a) NRL Confidential Report #3807 by H.L. Saxton et al, 15 June 1951 U)

1. Reference (a) is one of the principal documents in the development of the 10-kilocycle long-range search sonar system. The 10-kc active sonar was one of the phases in the reduction of the operating frequency of active sonars following World War II. The major frequency of sonars during World War II was 25 kHz. The research and development at NRL following the war progressed to 10 kHz, 5 kHz, and 2 kHz. This report discusses the design and configuration of the experimental 10-kc system.

2. The technology and equipment of reference (a) have long been superseded. The current value of this report is historical.

3. Based on the above, it is recommended that reference (a) be declassified and released with no restrictions.

Burton G. Hurdle

BURTON G. HURDLE
Acoustics Division

CONCUR:

E B Palmer 12/5/96

EDWARD R. FRANCHI Date
Superintendent
Acoustics Division